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A Primer on Unique Signal Stronglinks

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A Primer on Unique Signal Stronglinks

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Abstract

The unique signal stronglink plays an important role in modern nuclear detonation safety. The principal nuclear safety themes are described, and the function of the stronglink in each safety theme is presented. The stronglink is divided into four generic subsystems, and the function of each subsystem is described. A few high-level fundamentals of stronglink design are presented for the benefit of new stronglink designers. Finally, a glossary of terms used frequently in discussions of stronglinks is included.

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A Primer on Unique Signal Stronglinks

Some Nuclear Safety Fundamentals

The three principal safety themes for nuclear weapons are isolation, incompatibility, and inoperability. Independence is considered by some to be the fourth principle of nuclear safety. The stronglink plays an important role in all four themes.

Isolation

The critical components necessary for a nuclear detonation are "isolated" from their surroundings by placing them within an energy barrier. The volume enclosed by the barrier is known as the "exclusion region." The barrier blocks all forms of energy at the levels sufficient to cause a nuclear yield of greater than the equivalent of 4 pounds of TNT. A perfect barrier will make a weapon perfectly safe.

However, the result of perfect isolation is not a functional weapon. To initiate a nuclear detonation, some energy must be permitted inside the exclusion region. An energy shutter is required. When the shutter is closed, it should form an integral part of the barrier; when the shutter is opened, it should readily transfer energy inside the exclusion region to cause a nuclear detonation. Providing the energy shutter is one function of the stronglink.

Incompatibility

Great care is taken to ensure that only a deliberate action opens the shutter. The action can originate from human intent or the delivery environments of the weapon. The stronglink serves as a combination lock that prevents weapon usage until the deliberate action occurs. The combination to the lock is a complex pattern of binary pulses. Each stronglink contains one pattern and can only be operated by the application of that pattern. There are several types of stronglinks, and each type of stronglink is operated with a different pattern. These patterns are analyzed to ensure that they are "incompatible" with naturally occurring signals and are known as unique signals. They are engineered so that the odds of their accidental generation from a naturally occurring source is far less than one chance in a million.

A stronglink is a mechanical device, which forms a part of the exclusion region barrier and, upon receipt of the correct unique signal, opens a shutter to permit the transfer of energy into the exclusion region. The stronglink is required to withstand assault from the environment and remain functional until specified critical environmental levels are surpassed.

Inoperability

There are no perfect barriers. At some level of abnormal environmental exposure, the energy from the surroundings becomes so intense that the barrier loses integrity; that is, the barrier melts or ruptures. Nuclear safety is ensured in this situation by incorporating environmental vulnerability into certain critical components. These components are known as weaklinks. As their name suggests, they perform the opposite function of the stronglink. The weaklink, which must be functional for a nuclear detonation, is designed to fail at relatively low environmental levels. These levels are low enough to ensure that the weaklink fails before the stronglink or barrier fails. Ideally, the weaklinks are collocated with the stronglink, so that both components experience the same environmental assault. Capacitors, which store electrical energy used to fire weapon detonators, are common weaklinks. The capacitor is designed using materials that have a relatively low melting temperature. In a jet fuel fire, for example, the materials in the capacitor will melt, and the capacitor will become irreversibly "inoperable" before the stronglink or barrier fails from thermal exposure. In this way, a weapon fails in a safe condition and in a predictable fashion.

Ideally, a weaklink should exist for every type of environment that could cause the stronglink or barrier to fail. It is universally accepted that the level of temperature created by a jet fuel fire will defeat the stronglink and barrier. The initial emphasis on weaklink design was to protect against a thermal environment. Weaklinks have been developed for high voltage. Other environments, such as mechanical crush, do not have a designated weaklink, although one is desired.

Independence

Typically, two different stronglinks, which are arranged serially, are used per weapon. Different stronglinks with different patterns are used to gain "independence." Suppose a stronglink is susceptible to failure because of a design flaw or a manufacturing problem. If two of the same stronglinks were used in the weapon and a problem was systematic, then no advantage would be gained. However, if a systematic problem causes the first stronglink to fail, the second, independent stronglink will still protect the weapon.

The Anatomy of a Stronglink

Various stronglinks are used in weapons today. Just like people, they come in different shapes and sizes, and, just like people, they are essentially the same under the skin. All stronglinks contain a prime mover, a mechanical discriminator, an energy-coupling element or shutter, and a position monitor.

Prime Mover

As the result of deliberate action, either from a human or the weapon itself, the stronglink receives the unique signal. The unique signal can be thought of as the command to the stronglink to open the shutter. Typically, the unique signal is composed of a series of electrical pulses. The prime mover is an energy transducer that converts the electrical energy into mechanical motion. In most stronglinks, the prime movers are rotary solenoids. The solenoids are tied to the discriminator and create discrete motions in the same pattern as the unique signal. These motions are used to enable the stronglink.

Discriminator

The unique signal is embedded within the discriminator, usually as notches on a "pattern wheel." The discriminator interrogates the unique signal to determine if it is correct. The discriminator can be thought of as a maze and the unique signal as a series of left-turn and right-turn instructions. If the correct left and right instructions are delivered, then a maze walker can navigate through the maze and enable the stronglink. If just one of the turning instructions is incorrect, the maze walker turns down a blind alley and is trapped.

The stronglink is considered safe at its initial position, known as "reset," and remains safe until the discriminator has received and processed the entire unique signal. If a wrong signal is received by the stronglink, then the discriminator locks. Additional electrical pulses to the prime mover cannot release the discriminator after it becomes locked. If the discriminator is locked, the weapon is inoperable until the weapon is dismantled and the stronglink is manually unlocked.

The probability that the correct unique signal is randomly generated is far less than one chance per million. The stronglink will lock if a wrong signal is attempted. If a weapon was involved in an accident where electrical pulses were delivered to the solenoids, it is probable that the discriminator would lock, because the accident will almost certainly generate an incorrect pattern. Therefore, successful navigation of the unique signal by the discriminator is considered unambiguous proof of human intent to cause a nuclear detonation.

Energy-Coupling Element

The stronglink can be enabled after the discriminator has interrogated the unique signal. The stronglink is enabled when the shutter is opened, that is, when the coupling element is aligned. Usually a series of drive pulses, which are not part of the unique signal, move the coupling element. Drive pulses are used to ensure that the stronglink remains safe throughout the entire unique signal. The coupling element can be thought of as simply a shutter. It connects a source of energy outside the exclusion region with a critical component inside the exclusion region. The connection is made by moving the element into a position allowing the transmission of energy, rather than by removing a barrier from an already aligned element.

Different detonation schemes require different forms of energy; therefore, different stronglinks contain different coupling elements. The first stronglinks contained simple electrical switches that physically rotated one piece of high-conductivity metal into contact with a stationary piece of conductive metal. Other forms of energy coupled through stronglinks are magnetic, kinetic, chemical, and optical. The following table shows a list of the different stronglink discriminators, their prime movers, and their energy-coupling scheme.

Descriptions of the Stronglinks

Discriminator	Prime Mover	Coupling Scheme	Energy
MC2969	Rotary Solenoids	Electrical Contacts	Electrical
MC2935	Rotary Solenoids	Electrical Contacts	Electrical
C Mod	Rotary Solenoids	Interrupted Transformer	Magnetic
D Mod	Rotary Solenoids	Interrupted Transformer	Magnetic
MSAD	Linear Solenoids	Explosive Pellet	Kinetic
DSSL	Rotary Solenoids	Explosive Pellet	Kinetic
Pin in Maze	Stepper Motor	Prism Alignment	Optical
Leaf Spring	Stepper Motor	Paste Explosive Valves	Chemical

As discussed earlier, two different stronglinks are used per weapon and are arranged serially. One stronglink is known as the intent stronglink; the other as the trajectory stronglink. The unique signal for the intent stronglink cannot be stored in the weapon and must be entered by a person. The pattern for the trajectory stronglink is frequently stored in a device known as a trajectory-sensing signal generator. Commonly, the trajectory stronglink signal passes through the coupling element of the intent stronglink, thereby providing an element of human intent to the trajectory stronglink.

Position Monitor

Nuclear safety requires that the stronglink contain two independent indications that it is in a safe position after assembly into the weapon. These indications are usually accomplished with one passive indicator and one active indicator. After assembly into the weapon, the stronglink is radiographed (X-rayed) for passive indication. To improve the radiographic image, high-density (tungsten or tantalum) parts are often installed in the stronglink. The active safe indicator is a position monitor. Monitors are typically adjusted to produce a signal at the initial (reset) position to provide reliability information as well as nuclear safety information. Caution is needed in the placement of the active monitor because the conduits to the monitor may act as an energy bypass of the barrier. Electrical contacts, magnetic inductance, optical diodes, and optical fibers have been used as reset monitors.

How Strong Must a Stronglink Be?

Compared to most weapon components, stronglinks are rugged and massive mechanical devices. This might seem unusual in a time when miniature computers are prevalent and routinely process millions of bits of information. Certainly, more complicated codes could be used with microprocessor-based safety devices. Unfortunately, electronic devices are not environmentally robust and do not always fail in a predictable manner. In spite of their advantages, electronic devices are more suitable as weaklinks than stronglinks.

The term "environment" has been used to describe actions of nature. All weapons are exposed to environments. The normal environments of a weapon is the sequence of conditions to which the weapon is exposed from its introduction into the stockpile to its delivery at the target. Normal environments are quantified and specified in the stockpile-to-target sequence (STS) document. All other environments are classified as abnormal. Response of the weapon during normal environments is a reliability concern; response of the weapon during abnormal environments is a nuclear safety concern.

Numerous abnormal environments exist, and they can occur alone or in combinations. Typical abnormal environments are fire, shock, crush, and high voltage. A different weaklink for each type of abnormal environment should be present. For example, high explosives can act as the thermal weaklink, while another device, like lightning arrester connectors, can be the weaklink for high voltage. The stronglink and its weaklinks must work together to prevent inadvertent detonation of a weapon in all combinations of abnormal environments.

In most cases, tests are performed to verify that the weaklink fails irreversibly before the stronglink fails. Stronglinks have been burned, crushed, smashed, and struck by lightning. Sometimes it is impossible to artificially create the abnormal environment necessary to test the system. In these cases, the system is verified by analysis or engineering judgment.

Nuclear Safety is No Secret

The presence of a stronglink in a weapon requires some rigor and knowledge from its potential user. After all, the user must know the unique signal to enable the stronglink. Offering an incorrect pattern to the stronglink will render a weapon inoperable. So, should information about stronglinks and the patterns that enable them be classified? The answer is no. Stronglinks and safety systems are incorporated into weapons for protection against the actions of nature and not of human beings. The Department of Energy wants the positive steps it takes to protect against inadvertent detonation to be generally available to the public.

Denying an adversary access to a weapon or disabling a weapon when loss of possession is imminent are command and control issues. Controlling access to weapons and controlling their use are completely separate issues and are dealt with by completely separate methods. Typically, these methods are classified.

Some Stronglink Design Fundamentals

Rather than attempt to include comprehensive guidance on stronglink design, only a few general principles will be presented.

Almost all stronglink designs can be fit into two categories: gate-drive devices and drive-drive devices. The gate is the part that changes the state of the discriminator. A gating discriminator has two states, one for each type of event (A or B) in the binary unique signal. The gate will change the device to accept either an A or B event. Driving refers to the advance of the pattern wheel. In a gate-drive device, there is only one set of parts that can advance the pattern wheel. Drive-drive devices differ because there are two sets of parts capable of driving the device. One set corresponds to the A events; one other set to the B events.

Another feature common to most stronglinks is the use of rotary solenoids as the prime movers and ratcheting mechanisms in the discriminator. This scheme is desirable because it can be used to limit the energy delivered to the discriminator. Regardless of the intensity of the voltage presented to the solenoids, they can only rotate between two physical restraints.

The energy to the solenoids is decoupled from the discriminator during the power stroke through the use of a ratchet. An elastic element, like a spring, is stretched during the power stroke of the solenoid. The energy stored in the spring drives the discriminator and returns the solenoid. Therefore, a fixed and consistent amount of energy is delivered to the discriminator during each event. Limited energy is considered the ideal to advance the pattern wheel, although many of the stronglinks fall short of the ideal. When the prime movers (solenoids or stepper motors) can directly load the locking elements of the discriminator, then high voltage to the solenoid is another class of abnormal environment that must be addressed during a safety evaluation.

An important design consideration for stronglinks is the minimization of first-order safety failures. A single part or feature, whose absence would prevent the discriminator from locking or remaining locked, is defined as a first-order failure. The part or feature might be absent because of rupture, shear, omission, or evaporation. The method used to remove the part or feature for the sake of analysis is insignificant in the first-order safety analysis.

Absence of the pattern wheel is a common first-order failure, because the driving elements can be envisioned to shear teeth or plow slots into the wheel. Absence of drive pawl springs and lock pawl springs can also be first-order failures, because environments, such as vibration, could move the pawl away from its locking position in the absence of an opposing spring force. Because springs are relatively delicate, and reliability information indicates moderate probability of failure (1 in 10,000), redundancy is employed to upgrade the failure of safety-critical springs to second-order failures.

Glossary

Abnormal Environment. Any form or magnitude of energy not specifically identified in the stockpile-to-target sequence (STS) document; that is, any environment not expected by the weapon's designers.

Barrier. The material that separates the critical detonation components from external energy forms and demarcates the exclusion region.

Code Wheel. The part within the discriminator with notches or teeth corresponding to the unique signal.

Collocation. The deliberate juxtaposition of the stronglink and weaklink within the exclusion region so that the links are subjected to the same environmental insult.

Coupling Element. A subsystem of the stronglink that permits energy transfer into the exclusion region. Coupling elements can be switch contacts, explosive pellets, magnetically permeable materials, optical prisms, etc.

Discriminator. A subsystem of the stronglink that interrogates the unique signal and either locks or enables the stronglink.

Enabled. The position of the stronglink where the coupling element is aligned and energy transfer through the stronglink is possible. (See *Safe.*)

Event. The advancement of the code wheel through one position. It is equivalent to a decision on the correctness of the unique signal.

Exclusion Region. A special volume, surrounded by a barrier, containing the firing and detonation systems and the necessary packaging and safety devices to keep out energy except during intended usage.

Incompatibility. A fundamental nuclear safety principle requiring the format of the driving signals and response characteristics of the load to be designed to ensure that unintended signals inadvertently connected to the load will not produce an undesired response.

Inoperability. A fundamental nuclear safety principle in which vulnerability is designed into a system so that it predictably and permanently ceases to function when the environment exceeds certain extremes, but before the isolation system becomes overwhelmed.

Isolation. A fundamental nuclear safety principle where critical detonation components are insulated from energy sources through the use of a barrier.

Locked. The state of the discriminator after an incorrect event. The discriminator is incapable of further motion or advancement until it is reset through human action.

Ratchet. A mechanism that consists of a wheel having inclined teeth into which a pawl drops so that motion can be imparted on the wheel. Ratchets are used to allow effective motion in one direction only.

Reset. The position of the stronglink before the first event of the unique signal.

Safe. All positions of the stronglink where energy transfer cannot occur. Reset and locked are both subsets of the safe condition. (See *Enabled.*)

Solenoid. A device that converts electrical energy into kinetic energy.

Stronglink. A mechanical device that forms a part of the exclusion region barrier and, upon receipt of the correct unique signal, opens a shutter to permit the transfer of energy to inside the exclusion region.

Thermal Race. A colloquial expression for comparing the time it takes for the weaklink to fail in a fire versus the time for the stronglink to become unpredictable.

Unique Signal. An encoded message, capable of actuating the stronglink, whose format is chosen to allow the stronglink to discriminate it from all other signals that may exist inside or outside the weapon system.

Weaklink. Selected components vital to the operation of the detonation system that are designed to respond predictably to certain levels and types of abnormal environments by becoming irreversibly inoperable.

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